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Amizur et al.

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(54) **CONSTRAINING INERTIAL NAVIGATION SYSTEM SOLUTION ACCORDING TO PEDOMETRICAL DATA**

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(51) **Int. Cl.**

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H04W 4/04	(2009.01)
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G01C 21/20	(2006.01)
H04W 4/02	(2009.01)

(52) **U.S. Cl.**
CPC ***H04W 4/043*** (2013.01); ***G01C 21/165*** (2013.01); ***G01C 21/206*** (2013.01); *H04W 4/02* (2013.01)

(58) **Field of Classification Search**
CPC H04W 4/02; H04W 4/043; A63B 2225/50; G01C 22/006; G01C 21/165; G01C 21/206
See application file for complete search history.

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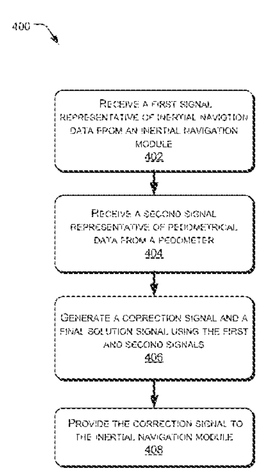
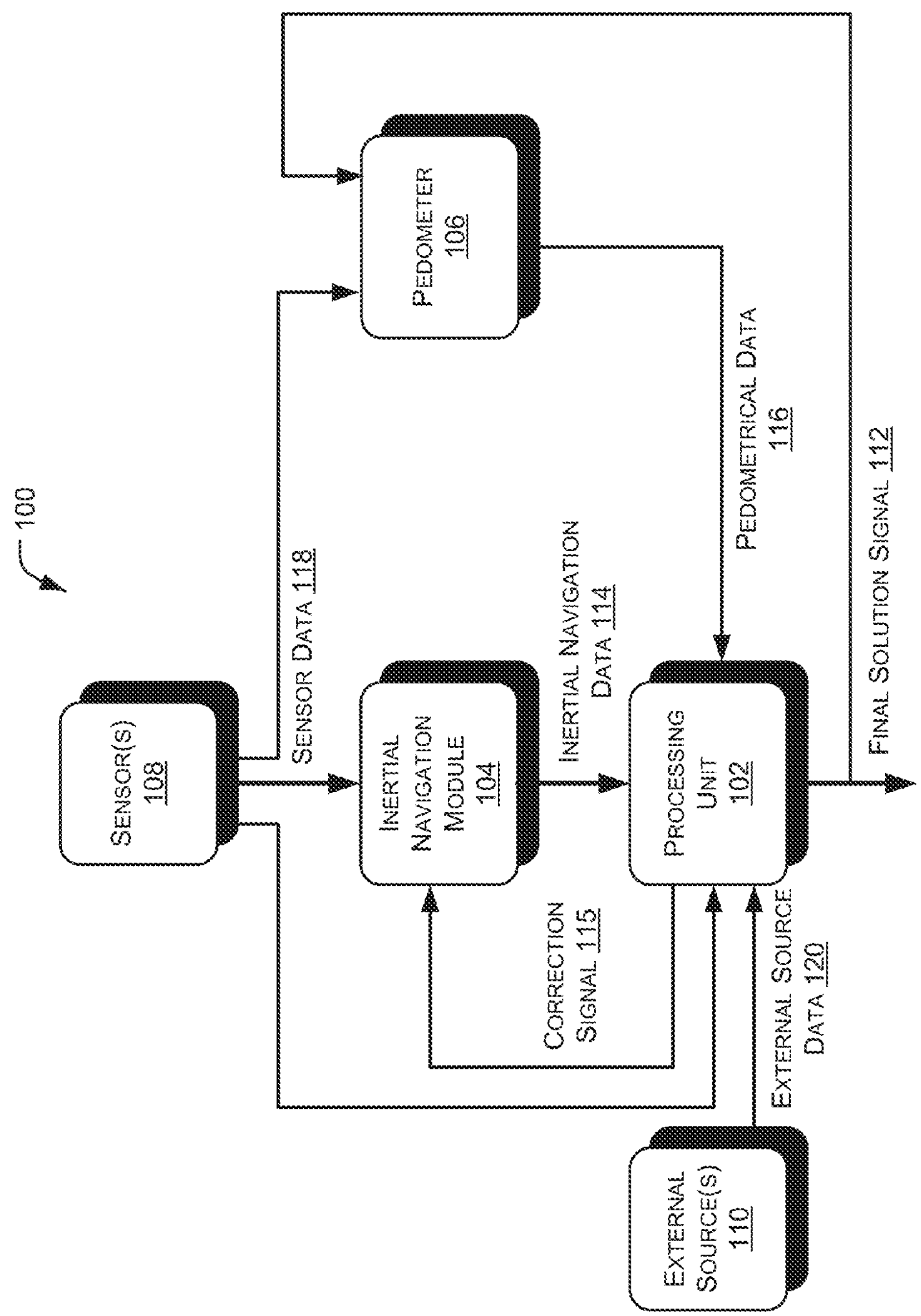
(57) **ABSTRACT**

Described herein are techniques related to constraining Inertial Navigation System (INS) solution according to pedometrical data. Data from sensors external to an inertial navigation module are leveraged in computing the final solution for indoor navigation. The techniques render the drift and divergence in inertial sensors to be much slower. Additionally, the techniques are not dependent on the attitude of the mobile device used for indoor navigation relative to the user's body.

31 Claims, 6 Drawing Sheets




100
Sensor(s)
108
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Inertial
Navigation
Module
104
Pedometer
106
Inertial Navigation
Data 114
Pedometrical Data
116
Processing
Unit
102
Final Solution Signal 112
Correction
Signal 115
External Source
Data 120
External
Source(s)
110

FIG. 1

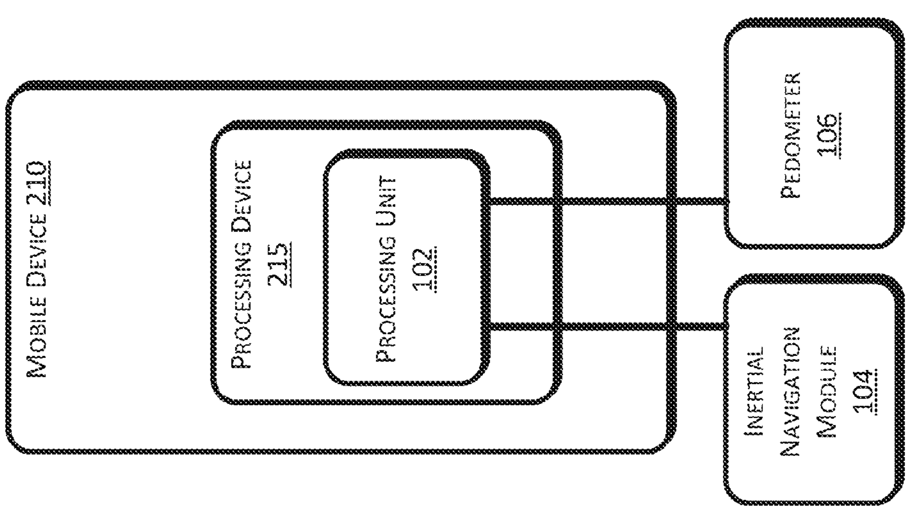

FIG. 2A

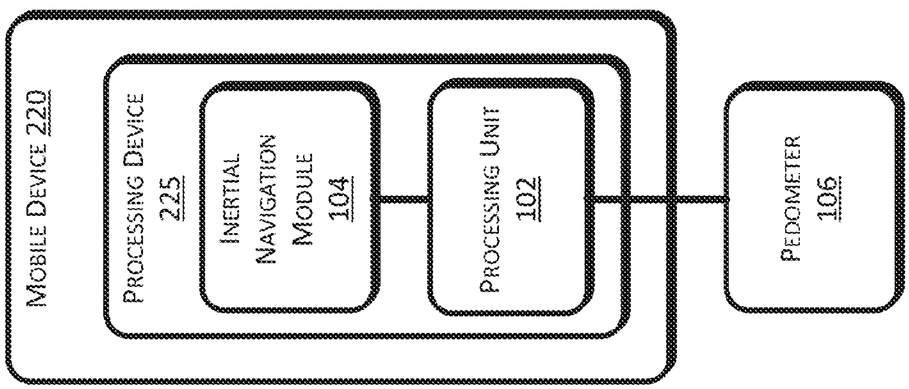

FIG. 2B

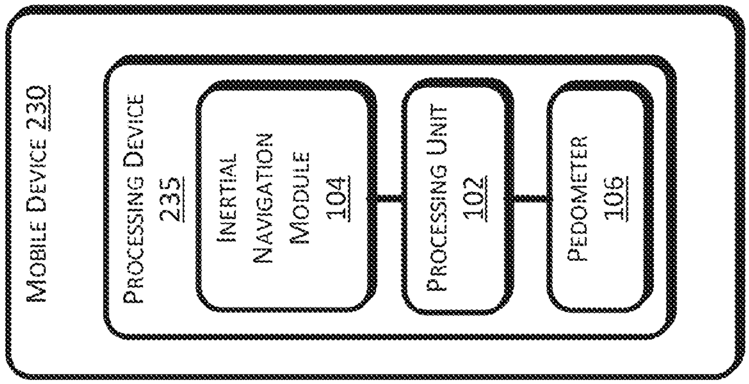

FIG. 2C

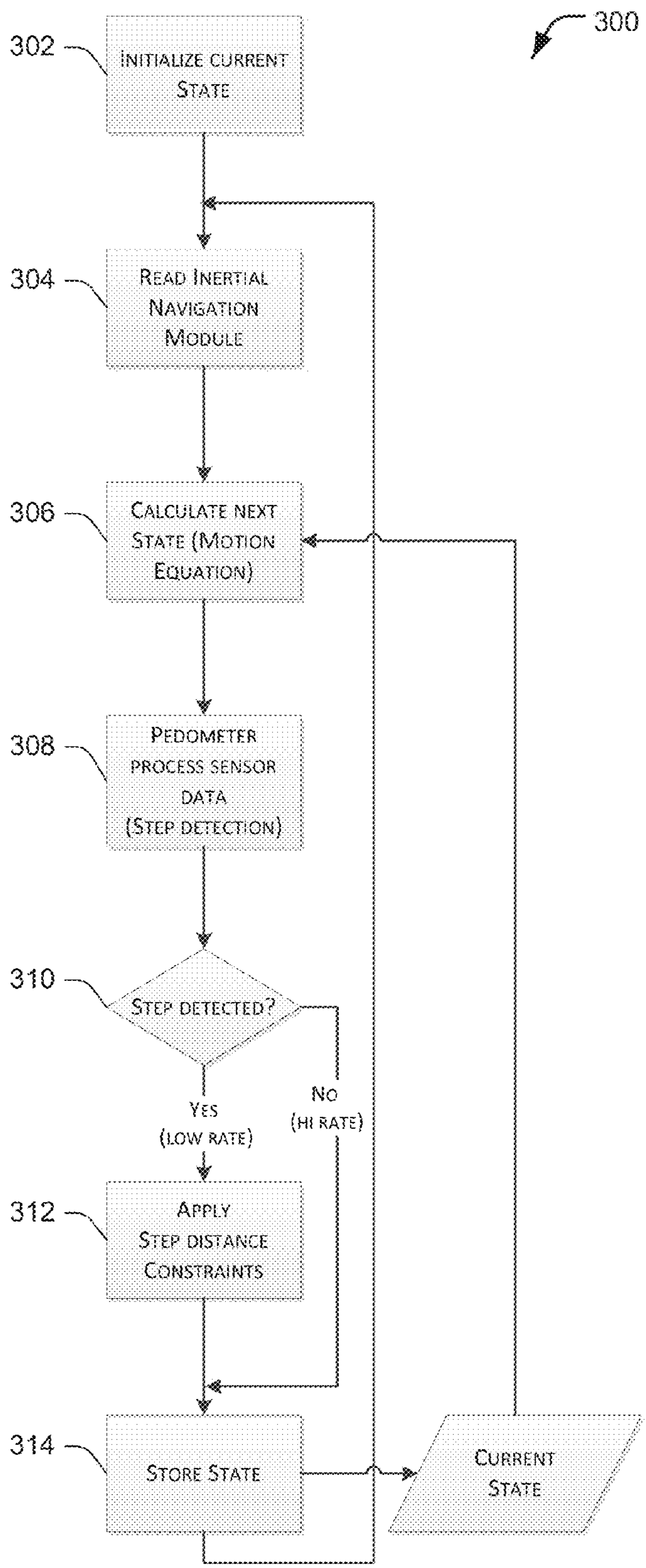
300
302
INITIALIZE CURRENT STATE
304
READ INERTIAL NAVIGATION MODULE
306
CALCULATE NEXT STATE (MOTION EQUATION)
308
PEDOMETER PROCESS SENSOR DATA (STEP DETECTION)
310
STEP DETECTED?
YES (LOW RATE)
NO (HI RATE)
312
APPLY STEP DISTANCE CONSTRAINTS
314
STORE STATE
CURRENT STATE

FIG. 3

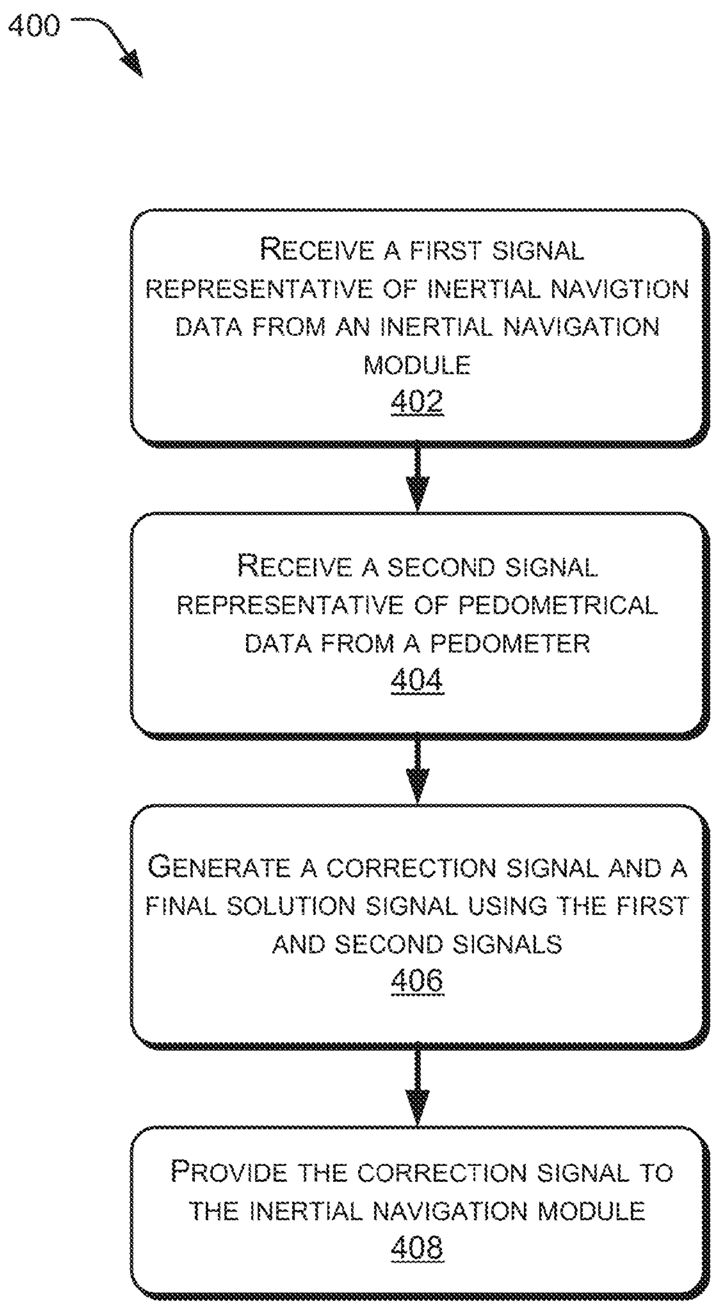
400
RECEIVE A FIRST SIGNAL REPRESENTATIVE OF INERTIAL NAVIGTION DATA FROM AN INERTIAL NAVIGATION MODULE
402
RECEIVE A SECOND SIGNAL REPRESENTATIVE OF PEDOMETRICAL DATA FROM A PEDOMETER
404
GENERATE A CORRECTION SIGNAL AND A FINAL SOLUTION SIGNAL USING THE FIRST AND SECOND SIGNALS
406
PROVIDE THE CORRECTION SIGNAL TO THE INERTIAL NAVIGATION MODULE
408

FIG. 4

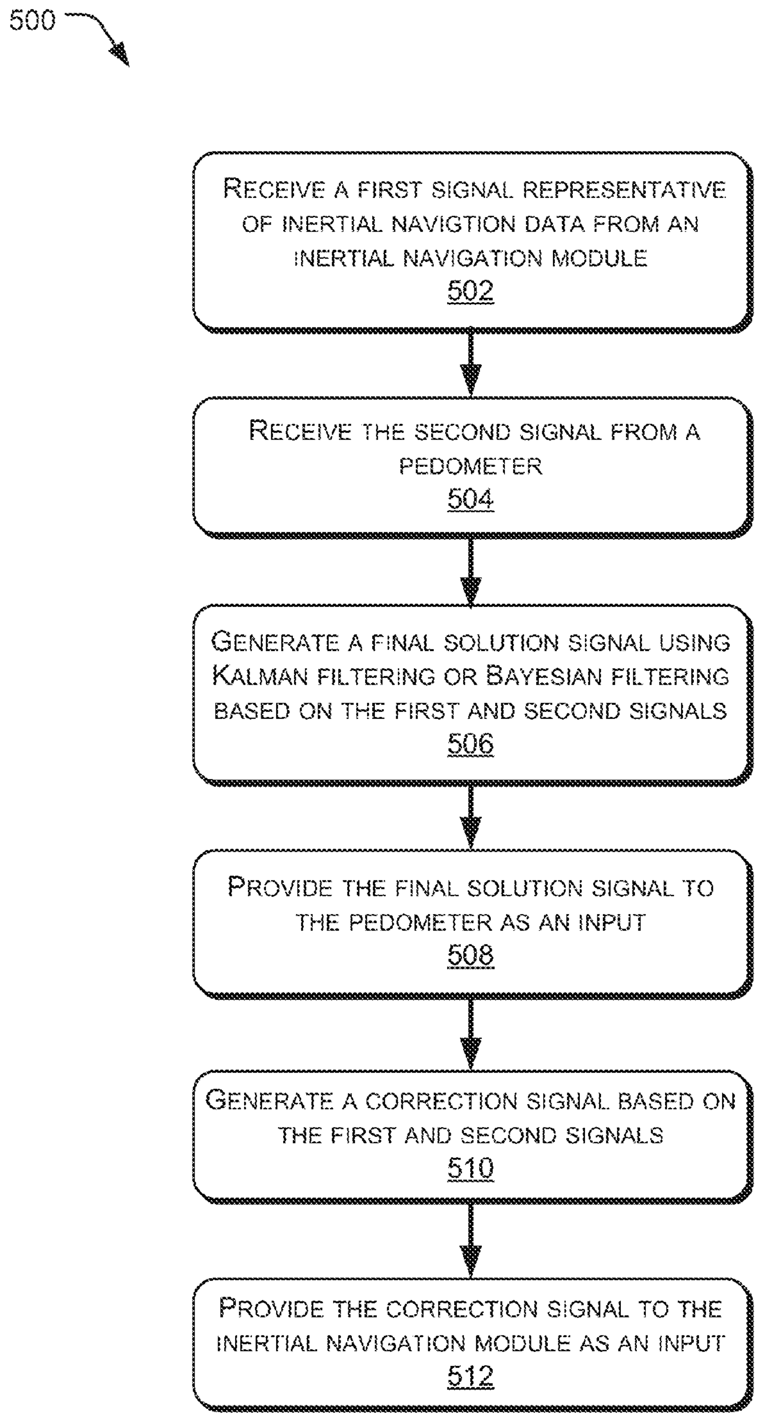
500
RECEIVE A FIRST SIGNAL REPRESENTATIVE OF INERTIAL NAVIGTION DATA FROM AN INERTIAL NAVIGATION MODULE
502
RECEIVE THE SECOND SIGNAL FROM A PEDOMETER
504
GENERATE A FINAL SOLUTION SIGNAL USING KALMAN FILTERING OR BAYESIAN FILTERING BASED ON THE FIRST AND SECOND SIGNALS
506
PROVIDE THE FINAL SOLUTION SIGNAL TO THE PEDOMETER AS AN INPUT
508
GENERATE A CORRECTION SIGNAL BASED ON THE FIRST AND SECOND SIGNALS
510
PROVIDE THE CORRECTION SIGNAL TO THE INERTIAL NAVIGATION MODULE AS AN INPUT
512

FIG. 5

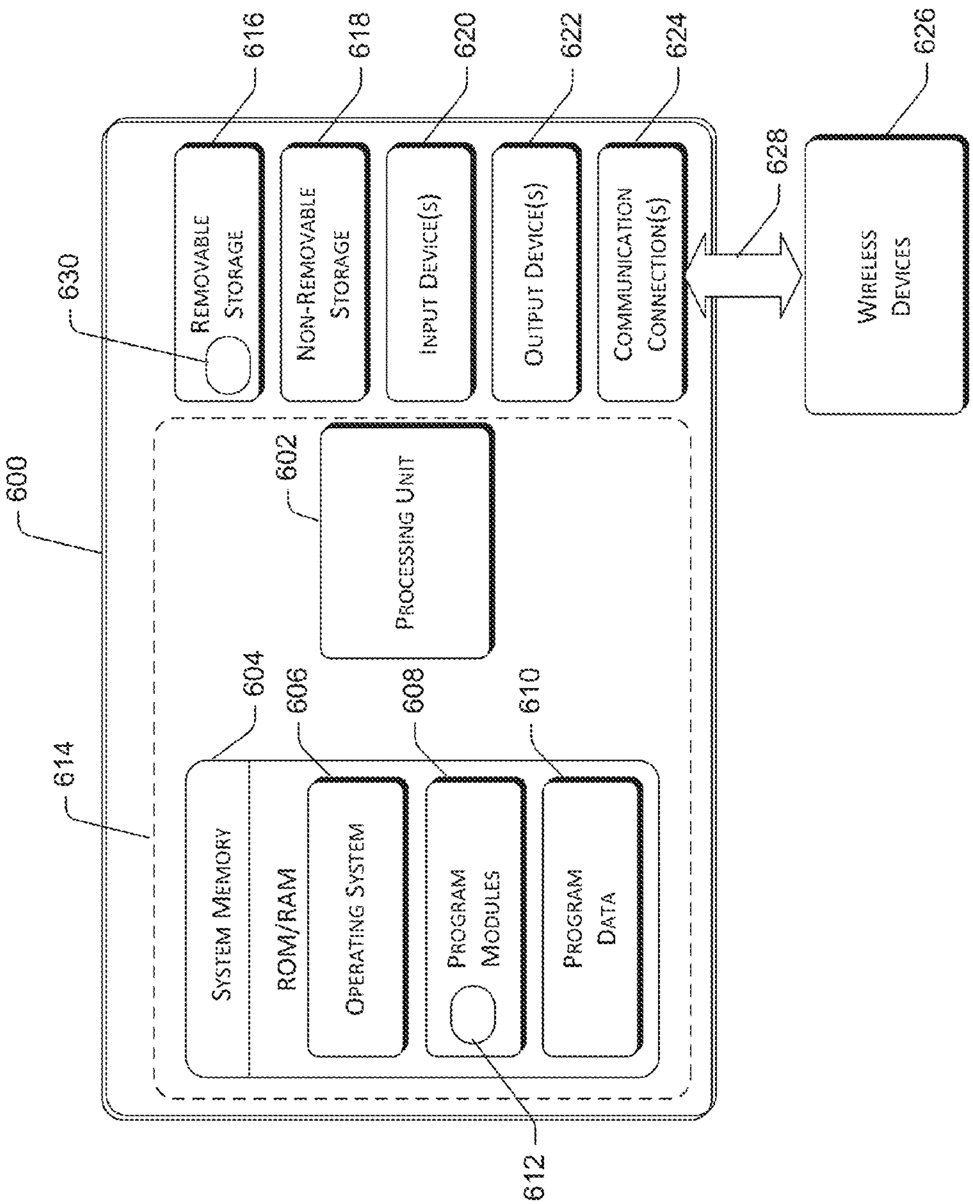
600
614
604
System Memory
ROM/RAM
606
Operating System
608
Program Modules
610
Program Data
612
602
Processing Unit
630
616
Removable Storage
618
Non-Removable Storage
620
Input Device(s)
622
Output Device(s)
624
Communication Connection(s)
628
626
Wireless Devices

FIG. 6

CONSTRAINING INERTIAL NAVIGATION SYSTEM SOLUTION ACCORDING TO PEDOMETRICAL DATA

BACKGROUND

As navigation using mobile devices, such as global positioning system (GPS) devices and smartphones equipped with GPS capability, becomes increasingly ubiquitous, the demand for extending this functionality indoors is on the rise. GPS, however, does not work well indoors as the satellite signals tend to be too weak indoors. Presently there exist a number of approaches to provide the indoor navigation functionality.

One approach is to utilize information provided by inertial navigation system (INS) that use low-cost inertial sensors and magnetometers, which are typically embedded in many mobile phones nowadays. Nevertheless, using these sensors to provide an indoor navigation solution tends to be problematic. For example, low-cost microelectromechanical system (MEMS) sensors tend to drift and diverge in a few seconds, resulting in inaccuracy. This alone may be enough reason to explain why such approach is not widely used today.

Another approach is to constrain the navigation results by mounting the sensors on the foot of a user and imposing zero velocity updates to the inertial calculation. However, mounting the sensor on the foot is not practical in many cases, for example when using a handheld device.

Another approach is to use a pedometer, which is an algorithm that count steps and estimate the trajectory according to the step length and the device attitude. However, there are several problems associated with this approach. Firstly, this approach depends very much on the way the user holds the mobile device. There is typically an assumption that the mobile device's attitude relative to the user's body is constant. This assumption renders this approach very limiting and not robust. Secondly, this approach depends on the length of the step of the user, which is unknown. Thirdly, this approach tends not to use most of the accelerometer information.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating an example framework implementing techniques of constraining inertial navigation system (INS) solution according to pedometrical data in accordance with the present disclosure.

FIGS. **2A-2C** are each a block diagram illustrating an example mobile device implementing techniques of constraining INS solution according to pedometrical data in accordance with the present disclosure.

FIG. **3** is a flow chart illustrating an implementation of constraining INS solution according to pedometrical data in accordance with the present disclosure.

FIG. **4** is a flow chart illustrating an example method for constraining INS solution according to pedometrical data in accordance with the present disclosure.

FIG. **5** is a flow chart illustrating another example method for constraining INS solution according to pedometrical data in accordance with the present disclosure.

FIG. **6** is a block diagram illustrating an example-computing device that implements techniques of constraining INS solution according to pedometrical data in accordance with the present disclosure.

The Detailed Description references the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The same numbers are used throughout the drawings to reference like features and components.

DETAILED DESCRIPTION

Disclosed herein are techniques, architectures, platforms, devices, framework and methods that constrain INS solution according to external sensor data such as pedometrical data. The techniques leverage data from sensors external to the INS in computing the final solution for indoor navigation. The techniques advantageously render the drift and divergence in inertial sensors to be much slower. Additionally, the techniques are not dependent on the attitude of the mobile device used for indoor navigation relative to the user's body.

For example, sensor data from an accelerometer, a gyroscope and/or a compass may be provided to the INS, or an inertial navigation module, as input. Pedometrical data from a pedometer may also be employed to constrain the INS by Kalman filtering or Bayesian filtering. From the filter a correction to the INS state is applied. The filter output provides a final solution for indoor navigation. Furthermore, data from other external sources, such as Wi-Fi ranges and/or global navigation satellite system (GNSS) pseudo ranges, may also be used in arriving at the final solution.

Example Framework

FIG. **1** illustrates an example framework **100** that implements techniques of constraining INS solution according to pedometrical data in accordance with the present disclosure.

As shown in FIG. **1**, the framework **100** includes a processing unit **102**, an inertial navigation module **104**, a pedometer **106**, one or more sensors **108**, and one or more external sources **110**. The inertial navigation module **104** is coupled to the processing unit **102** and outputs a first signal, representative of inertial navigation data **114**, to the processing unit **102**. In addition to the first signal from the inertial navigation module **104**, the processing unit **102** receives one or more additional inputs. The processing unit **102** may receive pedometrical data **116** from the pedometer **106**. Additionally or alternatively, the processing unit **102** may receive sensor data **118** from the one or more other sensors **108** such as, for example, an accelerometer, a gyroscope and/or a compass, or a combination thereof. Additionally or alternatively, the processing unit **102** may receive external source data **120** from the one or more external sources **110**, and the external source data **120** may be, for example, one or more ranges from a Wi-Fi system, one or more GNSS pseudo ranges from a GNSS, data related to a map or layout of a building, or a combination thereof. That is, the one or more additional inputs received by the processing unit **102** may come from the pedometer **106**, the one or more sensors **108** or the one or more external sources **110**, or a combination thereof. Based on the one or more additional inputs, the processing unit **102** constrains the inertial navigation data **114** from the inertial navigation module **104** and generates a final solution signal **112**. In some embodiments, the processing unit **112** further generates a correction signal **115**. The final solution signal **112** may be representative of the location, attitude, motion, velocity, acceleration and/or direction of a user, and is used for the purpose of indoor navigation for the user. The correction signal **115** is provided as an input to the inertial navigation module **104**. In some embodiments, the corrected signal **114** is different from the final solution signal **112**. In some embodiments, the corrected signal **114** is the same as the final solution signal **112**.

In some embodiments, the processing unit **102** provides the final solution signal **112** to the pedometer **106** as input to the pedometer **106** such that the pedometer **106** outputs a second signal representative of the pedometrical data **116**. Upon receiving the pedometrical data **116**, the processing unit **102** may update the final solution signal **112**. The processing unit **112** may further generate the correction signal **115** using the inertial navigation data **114** of the first signal and the pedometrical data **116** of the second signal.

In some embodiments, the processing unit **102** includes a Kalman filter. More specifically, the processing unit **102** may include the software, middleware, firmware, hardware, or a combination thereof that implements the functionality of a Kalman filter. In some embodiments, the processing unit **102** includes a Bayesian filter. More specifically, the processing unit **102** may include the software, middleware, firmware, hardware, or a combination thereof that implements the functionality of a Bayesian filter. In other embodiments, the processing unit **102** includes a suitable filter that filters the inertial navigation data **114** of the first signal and the data of the one or more inputs, such as the pedometrical data **116**, the sensor data **118** and the external source data **120**, to generate the final solution signal **112**.

In some embodiments, the inertial navigation module **104** may utilize one or more motion equations to generate the first signal representative of the inertial navigation data **114**. For example, the inertial navigation module **104** may utilize motion equations for an Earth-Centered, Earth-Fixed (ECEF) coordinate system, such as those shown below.

$$C_b^e(+) \approx C_b^e(-) \cdot (I_3 + \Omega_{ib}^b \cdot \tau_i) - \Omega_{ie}^e \cdot C_b^e(-) \cdot \tau_i \qquad \text{Equation 1}$$

$$v_{eb}^e(+) \approx v_{eb}^e(-) + \overbrace{(f_{ib}^e + g_b^e - 2 \cdot \Omega_{ie}^e \cdot v_{eb}^e(-))}^{a_{eb}^e} \cdot \tau_i \qquad \text{Equation 2}$$

$$r_{eb}^e(+) \approx r_{eb}^e(-) + (v_{eb}^e(+) + v_{eb}^e(-)) \cdot \tau_i / 2 \qquad \text{Equation 3}$$

In the above motion equations, (−) refers to the old value, (+) refers to the new calculated value, C_b^e is the rotation matrix between body frame and the ECEF frame, I_3 is a standard 3-by-3 diagonal matrix, Ω_{ie}^e Is the skew-symmetric matrix of the earth angular velocity, τ is the time between updates, v_{eb}^e is the velocity between body and the ECEF frame, f_{ib}^b is the specific force measured by the accelerometer, Ω_{ib}^b is the angular rate measured by the gyroscope, g_b^e is the gravitation of the earth, and r_{eb}^e is the distance between body and the ECEF frame and is also the position vector.

In some embodiments, the inertial navigation module **104** receives the sensor data **118** from the one or more sensors **108** as input. Using the sensor data **118**, the inertial navigation module **104** generates the first signal that represents the inertial navigation data **114**. In embodiments where the inertial navigation module **104** also receives as input the correction signal **115** from the processing unit **102**, the inertial navigation module **104** generates the first signal using the correction signal **115** and the sensor data **118**.

In some embodiments, the pedometer **106** receives the sensor data **118** from the one or more sensors **108** as input. Using the sensor data **118**, the pedometer **106** generates the second signal that represents the pedometrical data **116**. In embodiments where the pedometer **106** receives as input the final solution signal **112** from the processing unit **102**, the pedometer **106** generates the second signal using the final solution signal **112**. In embodiments where the pedometer **106** also receives as input the final solution signal **112** from the processing unit **102** and the sensor data **118** from the one or more sensors **108**, the pedometer **106** generates the second signal using the final solution signal **112** and the sensor data **118**.

Example Mobile Devices

FIGS. **2**A-**2**C each illustrates an example of implementing the framework **100** with respect to a mobile device **210**, **220** or **230**, respectively. Each of the mobile devices **210**, **220** and **230** may be, for example, a portable electronic device, a handheld device, a personal digital assistant, a smartphone or a portable computing device such as a tablet computer, a notebook computer, or a laptop computer.

As shown in FIG. **2**A, the processing unit **102** is part of the mobile device **210** while the inertial navigation module **104** and the pedometer **106** are external to the mobile device **210**. The processing unit **102** may be implemented in the form of firmware, hardware, a combination thereof, or a combination with software or middleware f. For example, the processing unit **102** may be implemented as a standalone integrated circuit (IC) or chip or, alternatively as shown in FIG. **2**A, as part of a processing device **215** which may include a chip, a chipset or a printed circuit board (PCB).

As shown in FIG. **2**B, the processing unit **102** and the inertial navigation module **104** are part of the mobile device **220** while the pedometer **106** is external to the mobile device **220**. Each of the processing unit **102** and the inertial navigation module **104** may be implemented in the form of firmware, hardware, a combination thereof, or a combination with software or middleware. For example, the processing unit **102** and the inertial navigation module **104** may be integral parts of a chip or may each be implemented in a separate chip. Alternatively, as shown in FIG. **2**B, the processing unit **102** and the inertial navigation module **104** may be part of a processing device **225**, which may include a chip, a chipset or a PCB.

As shown in FIG. **2**C, the processing unit **102**, the inertial navigation module **104** and the pedometer **106** are part of the mobile device **230**. Each of the processing unit **102**, the inertial navigation module **104** and the pedometer **106** may be implemented in the form of firmware, hardware, a combination thereof, or a combination with software or middleware. For example, the processing unit **102**, the inertial navigation module **104** and the pedometer **106** may be integral parts of a chip or may each be implemented in a separate chip. Alternatively, as shown in FIG. **2**C, the processing unit **102**, the inertial navigation module **104** and the pedometer **106** may be part of a processing device **235**, which may include a chip, a chipset or a PCB.

Example Processes

FIGS. **3**, **4** and **5** are flow diagrams illustrating example processes **300**, **400** and **500** that implement the techniques described herein for constraining INS solution according to pedometrical data. The order in which the process operations of example processes **300**, **400** and **500** is described is not intended to be construed as a limitation, and any number of the described process operations may be combined in any order to implement the process, or alternate process. Additionally, individual operations may be deleted from the process without departing from the spirit and scope of the subject matter described herein. Furthermore, the process may be implemented in any suitable hardware, software, firmware, or a combination thereof, without departing from the scope of the present disclosure.

FIG. **3** illustrates a process **300** for constraining INS solution according to pedometrical data in accordance with the present disclosure. The process **300** is performed, at least in part, by the processing unit **102**, the inertial navigation module **104**, and the pedometer **106** as described above.

The process **300** begins at operation **302**, where one or more values representative of a current state are initialized to that of an initial state. For example, the one or more values may indicate location, position, direction, velocity, acceleration, or a combination thereof, and such values are initialized, e.g., set to zero or a defined value. As the process **300** progresses, the one or more values are modified relative to their initial values at the initial state.

At operation **304**, an output signal of an inertial navigation module is read. For example, the inertial navigation module **104** reads the one or more sensors **108** by receiving as input the sensor data **118**.

At operation **306**, one or more values representative of a next state are calculated for state estimation. For example, the inertial navigation module **104** may calculate the one or more values for the next state by using motion equations.

At operation **308**, a pedometer processes sensor data or state estimation done in operation **306**. For example, the pedometer **106** may process inertial sensor readings as part of the sensor data **118** received from the one or more sensors **108**. Alternatively, the pedometer **106** may process the final solution signal **112**, which represents state estimation.

At operation **310**, steps taken by a user are detected to identify a pattern. Once a pattern is identified, the pedometer outputs an indication for each step, e.g., once every many iterations of the process **300**. For example, when the pedometer **106** identifies a pattern of steps of a user, the pedometer **106** may output the second signal representative of pedometrical data **116**, e.g., a distance between two consecutive steps, as an input to the processing unit **102**.

At operation **312**, step distance constraints are applied to INS solution of the inertial navigation module. In other words, when the step indication is output by the pedometer, step distance/length estimation is used to update the one or more values of the current state by constraining the possible solution set. For example, the processing unit **102** applies the pedometrical data **116** as constraints to the inertial navigation data **114** received from the inertial navigation module **104**. This may be performed by Kalman filtering or Bayesian filtering, for example.

At operation **314**, the one or more values representative of the current state are stored. For example, the one or more values representative of the current state may be stored in the inertial navigation module **104**.

The process **300** reiterates and starts from operation **304**. The one or more values representative of the current state are used in state estimation as performed in operation **306** by; for example, the inertial navigation module **104**.

FIG. **4** illustrates the example process **400** for constraining INS solution according to pedometrical data. The process **400** is performed, at least in part, by the processing unit **102** as described above.

The process **400** begins with operation **402**, where a first signal representative of inertial navigation data is received from an inertial navigation module. For example, as shown in FIG. **1**, the processing unit **102** receives the first signal representative of inertial navigation data **114** from the inertial navigation module **104**.

At operation **404**, a second signal representative of pedometrical data is received from a pedometer. For example, as shown in FIG. **1**, the processing unit **102** receives the second signal representative of pedometrical data **116** from the pedometer **106**.

At operation **406**, a correction signal and a final solution signal are generated using the first and second signals. For example, as shown in FIG. **1**, the processing unit **102** generates and outputs the correction signal **115** and the final solution signal **112** using the first signal representative of the inertial navigation data **114** and the second signal representative of the pedometrical data **116**.

The process **400** may optionally execute an additional operation **408**. At operation **408**, the correction signal is provided to the inertial navigation module. For example, as shown in FIG. **1**, the processing unit **102** provides the correction signal **115** to the inertial navigation module **104** as an input to the inertial navigation module **104**.

In some embodiments, the process **400** may further include receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof at the pedometer as input to the pedometer. For example, as shown in FIG. **1**, the processing unit **102** also receives the sensor data **118** from the one or more sensors **108** that may include one or more of a gyroscope, an accelerometer, and a compass.

In some embodiments, the process **400** may further include providing the final solution signal to the pedometer as input to the pedometer. For example, as shown in FIG. **1**, the processing unit **102** generates and outputs the final solution signal **112**, which is provided to the pedometer **106** as an input.

In some embodiments, the process **400** may further include receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof at the inertial navigation module as input to the inertial navigation module. For example, as shown in FIG. **1**, the inertial navigation module **104** receives the sensor data **118** from the one or more sensors **108** as input.

In some embodiments, the process **400** may further include receiving external source data from one or more external sources. The correction signal and the final solution signal may be generated using the first signal, the second signal, and the external source data. For example, as shown in FIG. **1**, the processing unit **102** receives the external source data **120** from the one or more external sources **110**, and generates and outputs the correction signal **115** and the final solution signal **112**. The external source data may include one or more GNSS pseudo ranges, one or more Wi-Fi ranges, data related to a map or layout of a building, or a combination thereof.

In some embodiments, the process **400** may further include receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof. The correction signal and the final solution signal may be generated using the first signal, the second signal, and the sensor data. For example, as shown in FIG. **1**, the processing unit **102** receives the first signal representative of inertial navigation data **114** form the inertial navigation module **104**, the second signal representative of pedometrical data **116** from the pedometer **106**, and the sensor data **118** from the one or more sensors **108** to generate and output the correction signal **115** and the final solution signal **112**.

In some embodiments, the processing unit **102** includes circuitry or logic that performs Kalman filtering, and the first signal representative of inertial navigation data **114** is filtered by Kalman filtering using the second signal representative of pedometrical data **116**, to provide the correction signal **115** and the final solution signal **112**.

In some embodiments, the processing unit **102** includes circuitry or logic that performs Bayesian filtering, and the first signal representative of inertial navigation data **114** is filtered by Bayesian filtering using the second signal representative of pedometrical data **116**, to provide the correction signal **115** and the final solution signal **112**.

FIG. **5** illustrates the example process **500** for constraining INS solution according to pedometrical data. The process **500** is performed, at least in part, by the processing unit **102** as described above.

The process **500** begins with operation **502**, where a first signal representative of inertial navigation data is received from an inertial navigation module. For example, as shown in

FIG. **1**, the processing unit **102** receives the first signal representative of inertial navigation data **114** from the inertial navigation module **104**.

At operation **504**, a second signal representative of pedometrical data is received from a pedometer. For example, as shown in FIG. **1**, the processing unit **102** receives the second signal representative of pedometrical data **116** from the pedometer **106**.

At operation **506**, a final solution signal is generated using Kalman filtering or Bayesian filtering based on the first signal and the second signal. For example, the processing unit **102** may include circuitry or logic that performs Kalman filtering or Bayesian filtering, and the processing unit **102** generates and outputs the final solution signal **112** using Kalman filtering or Bayesian filtering based on the first signal representative of inertial navigation data **114** received from the inertial navigation module **104** and the second signal representative of pedometrical data **116** received from the pedometer **106**.

At operation **508**, the final solution signal is provided to the pedometer as input such that the pedometer outputs the second signal representative of pedometrical data. For example, as shown in FIG. **1**, the pedometer **106** receives the final solution signal **112** as an input and outputs the second signal representative pedometrical data **116**.

The process **500** may optionally execute additional operations **510** and **512**. At operation **510**, a correction signal is generated based on the first and second signals. For example, the processing unit **102** generates the correction signal **115** based on the first signal representative of inertial navigation data **114** and the second signal representative of pedometrical data **116**. At operation **512**, the correction signal is provided to the inertial navigation module as an input. For example, as shown in FIG. **1**, the processing unit **102** provides the correction signal **115** to the inertial navigation module **104** as an input to the inertial navigation module **104**.

In some embodiments, the process **500** may further include receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof at the pedometer as input to the pedometer. For example, as shown in FIG. **1**, the pedometer **106** receives the sensor data **118** from the one or more sensors **108** as input.

In some embodiments, the process **500** may further include receiving external source data from one or more external sources. The correction signal and the final solution signal may be generated using the first signal, the second signal, and the external source data. For example, as shown in FIG. **1**, the processing unit **102** also receives the external source data **120** from the one or more external sources **110** in addition to receiving the first signal and the second signal, and generates and outputs the correction signal **115** and the final solution signal **112**. The external source data may include one or more GNSS pseudo ranges, one or more Wi-Fi ranges, data related to a map or layout of a building, or a combination thereof.

In some embodiments, the process **500** may further include receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof. The final solution signal may be generated using the first signal and the sensor data. For example, as shown in FIG. **1**, the processing unit **102** also receives the sensor data **118** from the one or more sensors **108** in addition to receiving the first signal and the second signal, and generates and outputs the correction signal **115** and the final solution signal **112**.

Example Mobile Devices

FIG. **6** illustrates an example computing device **600** that implements the scheme of constraining INS solution according to pedometrical data. However, it will be readily appreciated that the techniques disclosed herein may be implemented in other computing devices, systems, and environments. The computing device **600** shown in FIG. **6** is one example of a computing device and is not intended to suggest any limitation as to the scope of use or functionality of the computer and network architectures.

In at least one implementation, computing device **600** typically includes at least one processing unit **602** and system memory **604**. Depending on the exact configuration and type of computing device, system memory **604** may be volatile (such as RAM), non-volatile (such as ROM, flash memory, etc.) or some combination thereof. System memory **604** may include an operating system **606**, one or more program modules **608**, and may include program data **610**. A basic implementation of the computing device **600** is demarcated by a dashed line **614**.

The program module **608** may include a module **612** configured to implement the one-tap connection and synchronization scheme as described above. For example, the module **612** may carry out one or more of the method **400** and method **400**, and variations thereof, e.g., the computing device **600** acting as described above with respect to the processing unit **102**, mobile device **210**, mobile device **220** or mobile device **230**.

Computing device **600** may have additional features or functionality. For example, computing device **600** may also include additional data storage devices such as removable storage **616** and non-removable storage **618**. In certain implementations, the removable storage **616** and non-removable storage **618** are an example of computer accessible media for storing instructions that are executable by the processing unit **602** to perform the various functions described above. Generally, any of the functions described with reference to the figures may be implemented using software, hardware (e.g., fixed logic circuitry) or a combination of these implementations. Program code may be stored in one or more computer accessible media or other computer-readable storage devices. Thus, the processes and components described herein may be implemented by a computer program product. As mentioned above, computer accessible media includes volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data. The terms "computer accessible medium" and "computer accessible media" refer to non-transitory storage devices and include, but are not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other non-transitory medium that may be used to store information for access by a computing device, e.g., computing device **600**, mobile device **210**, mobile device **220** and mobile device **230**. Any of such computer accessible media may be part of the computing device **600**.

In one implementation, the removable storage **616**, which is a computer accessible medium, has a set of instructions **630** stored thereon. When executed by the processing unit **602**, the set of instructions **630** cause the processing unit **602** to execute operations, tasks, functions and/or methods as described above, including method **300**, method **400** and any variations thereof.

Computing device **600** may also include one or more input devices **620** such as keyboard, mouse, pen, voice input device, touch input device, etc. Computing device **600** may additionally include one or more output devices **622** such as a display, speakers, printer, etc.

Computing device **600** may also include one or more communication connections **624** that allow the computing device **600** to communicate wirelessly with one or more other wireless devices, over wireless connection **628** based on near field communication (NFC). Wi-Fi, Bluetooth, radio frequency (RE), infrared, or a combination thereof.

It is appreciated that the illustrated computing device **600** is one example of a suitable device and is not intended to suggest any limitation as to the scope of use or functionality of the various embodiments described.

Additional and Alternative Implementation Notes

Unless the context indicates otherwise, the term "INS" as used herein includes inertial sensors, magnetometers, MEMS or any suitable means that may output information useful for inertial navigation purposes.

In the above description of example implementations, for purposes of explanation, specific numbers, materials configurations, and other details are set forth in order to better explain the present invention, as claimed. However, it will be apparent to one skilled in the art that the claimed invention may be practiced using different details than the example ones described herein. In other instances, well-known features are omitted or simplified to clarify the description of the example implementations.

The inventors intend the described example implementations to be primarily examples. The inventors do not intend these example implementations to limit the scope of the appended claims. Rather, the inventors have contemplated that the claimed invention might also be embodied and implemented in other ways, in conjunction with other present or future technologies.

The term "techniques," for instance, may refer to one or more devices, apparatuses, systems, methods, articles of manufacture, and/or computer-readable instructions as indicated by the context described herein.

As used in this application, the term "or" is intended to mean an inclusive "or" rather than an exclusive "or." That is, unless specified otherwise or clear from context, "X employs A or B" is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then "X employs A or B" is satisfied under any of the foregoing instances. In addition, the articles "a" and "an" as used in this application and the appended claims should generally be construed to mean "one or more," unless specified otherwise or clear from context to be directed to a singular form.

These processes are illustrated as a collection of blocks in a logical flow graph, which represents a sequence of operations that may be implemented in mechanics alone or a combination with hardware, software, middleware and/or firmware. In the context of software/firmware, the blocks represent instructions stored on one or more computer-readable storage media that, when executed by one or more processors, perform the recited operations.

Note that the order in which the processes are described is not intended to be construed as a limitation, and any number of the described process blocks may be combined in any order to implement the processes or an alternate process. Additionally, individual blocks may be deleted from the processes without departing from the spirit and scope of the subject matter described herein.

The term "computer-readable media" and "computer accessible media" include computer-storage media. For example, computer-storage media may include, but are not limited to, magnetic storage devices (e.g., hard disk, floppy disk, and magnetic strips), optical disks (e.g., compact disk (CD) and digital versatile disk (DVD)), smart cards, flash memory devices (e.g., thumb drive, stick, key drive, and SD cards), and volatile and non-volatile memory (e.g., random access memory (RAM), read-only memory (ROM)).

Unless the context indicates otherwise, the term "logic" used herein includes hardware, software, firmware, circuitry, logic circuitry, integrated circuitry, other electronic components and/or a combination thereof that is suitable to perform the functions described for that logic.

What is claimed is:

1. A method comprising:

receiving, by a processing unit of a processing device of a mobile device, a first signal representative of inertial navigation data from an inertial navigation module, wherein the inertial navigation module utilizes one or more sensors physically located with a user;

receiving, by the processing unit of the processing device of the mobile device, a second signal representative of pedometrical data from a pedometer, wherein the pedometer utilizes the one or more sensors physically located with the user;

generating, by the processing unit of the processing device of the mobile device, a correction signal using the first and second signals; and

generating, by the processing unit of the processing device of the mobile device, a final solution signal by Kalman filtering or Bayesian filtering the first and second signals.

2. A method as recited in claim **1**, wherein the first signal representative of inertial navigation data is generated by the inertial navigation module using one or more motion equations, and wherein generating the correction signal and the final solution signal using the first and second signals comprises Kalman filtering the first and second signals to provide the correction signal and the final solution signal.

3. A method as recited in claim **1**, wherein the first signal representative of inertial navigation data is generated by, the inertial navigation module using one or more motion equations, and wherein generating the correction signal and the final solution signal using the first and second signals comprises Bayesian filtering the first and second signals to provide the correction signal and the final solution signal.

4. A method as recited in claim **1** further comprising: providing the correction signal to the inertial navigation module as input to the inertial navigation module such that the inertial navigation module outputs the first signal based at least in part on the correction signal.

5. A method as recited in claim **1** further comprising: receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof at the pedometer as input to the pedometer.

6. A method as recited in claim **1** further comprising: providing the final solution signal to the pedometer as input to the pedometer such that the pedometer outputs the second signal based at least in part on the final solution signal.

7. A method as recited in claim **1** further comprising: receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof at the inertial navigation module as input to the inertial navigation module.

8. A method as recited in claim **1** further comprising: receiving external source data from one or more external sources, wherein generating the correction signal and the final solution signal using the first and second signals comprises generating the correction signal and the final solution signal using the first signal, the second signal, and the external source data.

9. A method as recited in claim **8**, wherein the external source data from the one or more external sources comprise one or more global navigation satellite system (GNSS) pseudo ranges, one or more Wi-Fi ranges, data related to a map, or a combination thereof.

10. A method as recited in claim **1** further comprising: receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof, wherein generating the correction signal and the final solution signal using the first and second signals comprises generating the correction signal and the final solution signal using the first signal, the second signal, and the sensor data.

11. A method comprising:

receiving, by a processing unit of a processing device of a mobile device, a first signal representative of inertial navigation data from an inertial navigation module, wherein the inertial navigation module utilizes one or more sensors physically located with a user;

receiving, by the processing unit of the processing device of the mobile device, a second signal representative of pedometrical data from a pedometer, wherein the pedometer utilizes the one or more sensors physically located with the user; satellite system (GNSS) pseudo ranges, one or more Wi-Fi ranges, data related to a map, or a combination thereof.

12. A method as recited in claim **11** further comprising: generating a correction signal based on the first and second signals; and providing the correction signal to the inertial navigation module as input to the inertial navigation module such that the inertial navigation module outputs the first signal based at least in part on the correction signal.

13. A method as recited in claim **11** further comprising: receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof at the pedometer as input to the pedometer.

14. A method as recited in claim **11** further comprising: receiving sensor data from a gyroscope, an accelerometer or a compass, a combination thereof at the inertial navigation module as input to the inertial navigation module.

15. A method as recited in claim **11** further comprising: receiving external source data from one or more external sources, wherein generating the correction signal and the final solution signal using the first and second signals comprises generating the correction signal and the final solution signal using the first signal, the second signal, and the external source data.

16. A method as recited in claim **15**, wherein the external source data from the one or more external sources comprise one or more global navigation satellite system (GNSS) pseudo ranges, one or more Wi-Fi ranges, data related to a map, or a combination thereof.

17. A method as recited in claim **11** further comprising: receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof, wherein generating the final solution signal using the first signal comprises generating the final solution signal using the first signal and the sensor data.

18. A device comprising:

an inertial navigation module that outputs a first signal representative of inertial navigation data, wherein the inertial navigation module utilizes one or more sensors physically located with a user; and

a processing unit of a processing device of the device, the processing unit being coupled to receive the first signal and at least a second signal representative of pedometrical data, the processing unit further configured to generate a final solution signal by Kalman filtering or Bayesian filtering the first and second signals and a correction signal using the first signal and the second signal, the correction signal received by the inertial navigation module as an input signal.

19. A device as recited in claim **18**, wherein the processing unit comprises a Kalman filter.

20. A device as recited in claim **18**, wherein the processing unit comprises a Bayesian filter.

21. A device as recited in claim **18**, wherein the processing unit further receives external source data from one or more external sources and generates the final solution signal and the correction signal using the first signal, the second signal, and the external source data.

22. A device as recited in claim **21**, wherein the external source data from the one or more external sources comprise one or more global navigation satellite system (GNSS) pseudo ranges, one or more Wi-Fi ranges, data related to a map, or a combination thereof.

23. A device as recited in claim **18**, wherein the processing unit further receives sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof and generates the final solution signal and the correction signal using the first signal, the second signal, and the sensor data.

24. A device as recited in claim **18**, wherein the inertial navigation module outputs the first signal using one or more motion equations.

25. A device as recited in claim **18**, wherein the inertial navigation module further receives sensor data from a gyroscope, an accelerometer, a compass, or a combination thereof and generates the first signal using the correction signal and the sensor data.

26. A device as recited in claim **18** further comprising: a pedometer that outputs pedometrical data as the second signal.

27. A device as recited in claim **26**, wherein the pedometer receives sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof and generates the second signal using the using the sensor data.

28. A device as recited in claim **26**, wherein the pedometer receives the final solution signal as an input signal and generates the second signal using the final solution signal.

29. At least one computer accessible medium having stored thereon a set of instructions that, when executed by one or more processors, direct the one or more processors to execute operations comprising: receiving a first signal representative of inertial navigation data from an inertial navigation module; receiving a second signal representative of pedometrical data from a pedometer; filtering the first and second signals through a Kalman filter or a Bayesian filter to provide a correction signal and a final solution signal; and providing the correction signal to the inertial navigation module as input to the inertial navigation module such that the inertial navigation module outputs the first signal based at least in part on the correction signal.

30. At least one computer accessible medium as recited in claim **29**, wherein the operations further comprise: receiving external source data from one or more external sources, wherein the filtering comprises filtering the first signal, the second signal, and the external source data, and wherein the external source data from the one or more external sources comprise one or more global navigation satellite system (GNSS) pseudo ranges, one or more Wi-Fi ranges, data related to a map, or a combination thereof.

31. At least one computer accessible medium as recited in claim **29**, wherein the operations further comprise: receiving sensor data from a gyroscope, an accelerometer or a compass, or a combination thereof, wherein the filtering comprises filtering the first signal, the second signal, and the sensor data.

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